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APPLICATION OF COMMERCIAL PARTS OBSOLESCENCE MANAGEMENT (CPOM)

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MATERIALS AND MANUFACTURING DIRECTORATE
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NOTICE

This technical report has been reviewed and is approved for publication.

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14. ABSTRACT
Northrop Grumman Electronic Systems (Baltimore, Maryland) in cooperation with the AFRL Material and Manufacturing Directorate (WPAFB, Ohio) developed a 58-month ManTech obsolescence program to pursue a diverse group of tasks in various areas of parts obsolescence. The objective of the program was to reliably use COTS parts in military systems, implement ManTech funded tools and processes, integrate tools and processes in the Northrop Grumman design environment, and document the resulting cost avoidance. The program has completed its work with notable success. This succinct report highlights the results and benefits.

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1.0 PROGRAM SUMMARY AND INTRODUCTION – CPOM

1.1 INTRODUCTION

Northrop Grumman has been pleased to carry out the Commercial Parts Obsolescence Management (CPOM) program under Cooperative Agreement F33615-99-2-5500. Under this agreement, AFRL Manufacturing Technology Division (ManTech) provided approximately 75% of the program funding, and Northrop Grumman provided 25%. Over the course of the program, we exceeded the required cost share by 27%. The program has been completed successfully within the funding provided.

CPOM began in June 1999, and was scheduled to run for 58 months, with an April 2004 completion. The program has been kept on schedule, with no delays or extensions, and is now being completed a couple of months early with the delivery of this Final Report.

The program was originally compiled from several proposals in different areas that were merged together. With this background, it has been an extremely diverse effort whose broad scope has provided many benefits to Northrop Grumman and our customers. The first phase of the program, called ACME for Application of Commercially Manufactured Electronics, developed a wide range of processes, tools, and analyses. The second phase of the program, the Pilot, successfully carried out its charter of documenting the benefits of the tools and processes in spite of a major redirection.

Since 1999, we have submitted 17 Quarterly Reports that have provided detailed information and documentation of results. These reports are a treasure trove of information on reliability, use and testing of COTS parts, process improvements, evaluation of groundbreaking tools, and analysis of chips and packages. In addition, we have participated in many Electronic Parts Obsolescence Initiative (EPOI) meetings to further share information with other contractors and members of the obsolescence community. Several presentations have also been made to AFRL personnel to highlight program successes and demonstrate the tools we have developed.

We now present this Final Report to succinctly summarize the benefits and successes that CPOM has attained. Comments and questions are invited to the contacts below:

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1.2 Executive Summary

CPOM addressed existing COTS obsolescence tools and process issues under the following headings.

- General Plastic Encapsulated Microcircuit (PEM) Issues -Qualification of commercial components.
- CPOM Packaging Issues - Application and testing of COTS parts.
- Reliability Prediction Comparisons - Evaluation and implementation of reliability models.
- Recommendations & Design Guidelines - Design rules and design capture
- Design Of The Environment - COTS part bonding and thermal issues
- Tool Development Assistance - Interaction with the tool developers of RADSS, DVTG, i2, MOCA and VP Technologies models.
- Titan Corporation Subcontract - Develop, integrate and test Poet software and Rosetta models. Integrate tools and Rosetta models using the Poet software suite. A workflow task was added in 2003 to automate Bill of Material analysis and design review checklists.
- Baseline Legacy System/Metrics - Establish Quantifiable Metrics, Collect baseline data.
- Improved Policies/Practices/ Procedures - Process improvements, Lean Corporate Processes/Practices.
- MOCA Evaluation - Evaluate MOCA on NGC test case and integrate MOCA with Poet.
- Georgia Tech Subcontract – Develop and verify Physics-based virtual reliability models.

Through the implementation of improved tools and processes, CPOM was able to demonstrate **more than $22M total cost avoidance** across multiple platforms on the pilot program.

Table 1-1 CPOM Cost Savings Demonstrated Across Northrop Grumman Electronic Systems

Tool	Previous Cost	Approach with CPOM	Savings
I2	Revision Notices Military parts required Manual New Part Request and Review	Evaluate part number and DMS issues at part selection COTS enabled Electronic NPR workflow, integrated to design tools	Revision cost avoidance **$>1.8M** annually **$>3M** annually See CDT metric
CDT	$9,400 per new part from Coopers and Lybrand	Use CDTs to standardize parts	**$~6.8M** annually in avoidance of new part introductions
Reliability Prediction	Program specific	Reduced search time, improved prediction, customer acceptance of methodology	**~$300,000** annually. Enables additional 55% of IC technology
CPT/Design Reuse	Program IPT	CPT product reviews and standardization	**$>11M** in '03. 23% design cycle time reduction for some products
RADSS	Minor redesign $22.4K to $111K Major redesign $200K to $770K from EIA bulletin GEB1	Demonstration tool. Avoid redesigns	Pilot case shows potential for ~$500K
DVTG (VectorGen)	VHDL capture	Demonstration tool only	Potential savings in reduction of redesign cost
VP Technologies	Typically not modeled	Demonstration tool only	Potential savings at AF Program Office level

1.3 Vision Statement

The primary objective of CPOM was to document the cost avoidance resulting from the implementation of obsolescence management tools, reliability tools, corporate initiative tools and lean corporate practices.

1.4 Goals and Objectives

In order to achieve the desired cost reductions, CPOM was required to demonstrate reliable use of Commercial Off-the-Shelf (COTS) parts in military systems, implement USAF ManTech funded tools and processes and Integrate tools and processes in the Northrop Grumman Electronic Systems Integrated Design Environment (IDE)

2.0 TECHNICAL TASKS AND RESULTS

2.1 General PEM Issues, Design Capture, Packaging Issues, Design of the Environment

CPOM established component test methodologies and qualification thresholds utilizing industry models and physics of failure analysis. When the program was initiated, we could find no industry experts who fully understood the various models. As the program progressed the models were rederived for various military application environments. The end results are very close to the models that are now defined in AEC Q100, STACK 001 and SSB-1. Along the way, a great deal was learned about how to apply the models in component selection and we gained the detailed knowledge to explain the processes to our customers, engineers and suppliers.

Northrop Grumman completed the baseline documentation of end of life failure mechanisms unique to PEM and incorporated the corrosion failure mechanism data and thermal stress failure mechanism data into our component qualification threshold requirements. Non-unique failure mechanisms are addressed in the same manner as has been done with hermetically sealed devices.

2.2 Packaging Issues

2.2.1 Chip-to-Board CTE Mismatch Testing

Chip-to-Board CTE Mismatch Testing was designed to fine tune design rules and establish thresholds for chips size versus board material to avoid thermomechanical fatigue failures. The primary focus of this testing was on chip devices and leadless chip carriers mounted on various substrates. Design rules were developed and incorporated into design reviews and new part selection processes. Since single layer, alumina based resistor chips represented the biggest potential problem area, that analysis was automated in the Bill of Material analysis tool by Titan Corporation.

2.2.2 40-mil BGA Testing

40-mil BGA Testing – Testing of various BGA sizes, pitches and constructions was performed under CRAD and IRAD available from other contracts and from Northrop Grumman internal funding. This information was incorporated into design rules and design review procedures developed under CPOM. A BGA steering committee was established to review new BGA packages selected for introduction into Northrop Grumman designs.

2.2.3 COTS Test Vehicle

The goal of this exercise was to evaluate a variety of COTS BGA formats for assembly and reliability and to determine the reliability impact of various underfills and mounting approaches. Candidate BGA, CSP COTS components and underfills were selected. Environmental test criteria were defined and a statistical test plan was developed that included thermal cycling and vibration testing. The test results showed that underfill helps, but is not required for near CTE-matched COTS parts to meet reliability requirements. Northrop Grumman evaluates the thermal compatibility each assembly and avoids underfill where possible in order to ease manufacturability and decrease cost. Underfill improved reliability for all cases except ceramic column grid arrays. We noted that “cavity”-down perimeter BGAs performed better than “cavity”-up full-area BGAs and that reliability improvements for ceramic BGA assemblies were not sufficient to meet program reliability requirements.

2.2.4 Alternate ASIC & MMIC Packaging Evaluation.

The goal of this research was to establish selection criteria for best format for COTS ASIC and MMIC packaging given alternate available configurations, to define preferred packaging format for near-term applications and to establish a roadmap for future format preferences. Internal and external surveys of parts preferences were performed for design engineering and manufacturing. Literature searches and reviews were conducted for preferences with respect to performance, reliability, and industry packaging trends. Near-term and long-term packaging format preferences were defined and design guidelines were modified to reflect findings.

While the flip chip format offers superior performance and packaging densities, current infrastructure does not support full implementation. Near-term parts selection is restricted to BGA and CSP formats having 0.75 mm pitch or greater, with smallest pitch parts preferred. High density interconnect (HDI) printed wire board technology is needed to use finer than 0.75 mm pitch components, but reliability of these is still being determined.

2.2.5 COTS RF & Digital Connectors

The goal of this design effort was to evaluate adaptation of COTS RF and Digital connectors for military environments and to reduce the cost of RF connectors.

The team worked with Amphenol, designing custom inserts for their standard product offering to accommodate several military program requirements for backplane connectors. Molds for these inserts were designed and procured. Upon receipt, these were tested for mechanical fit and electrical performance. The new connectors were subjected to environmental

and reliability testing for insertion into future products. These connectors have become the standard connectors for module interfaces.

An additional team activity was to work with COTS RF connector suppliers Gore and Gilbert Engineering by designing and prototyping new, smaller high performance RF connectors. The new connectors are 60% the size of Gilbert GPPO connectors. These are planned for commercialization by Gore under their Mini-SMP-100 product line.

Sample connectors were delivered and parts were successfully incorporated into the design of one of our common radar modules.

Concurrently, testing was conducted on these parts by Gore. As expected, performance of these parts exceeded current GPO/SMP and GPPO/Mini-SMP specifications with no substantial increase in cost, while significantly reducing the size.

2.2.6 Design of the Environment

Design of the Environment. Packaging evaluation was undertaken as a means of understanding the impact on manufacturing processes driven by the use of COTs components. Many misunderstandings existed with respect to COTs packaging consistency. Dimensions and stand-off height were measured and determined to be very consistent across manufacturers for components in the same family, same part number and same package types. This put to bed a popular excuse for not using COTs and enabled manufacturing processes to be standardized and documented. It was determined that the majority of inconsistencies found on the PEMs' stand-off height were due to handling issues and could be addressed using basic material handling controls. Northrop Grumman documents packaging for automated handling in the product data management system and electronically flows it down to suppliers on the purchase order. This provides an additional checkpoint for design reviews as packaging information is readily available to manufacturing well before any material is placed on order or delivered to the factory floor. Upon receipt packaging is verified and stocked in as received condition thus eliminating multiple handling and repackaging steps.

Die orientation within integrated circuit packages was evaluated for impact on thermal dissipation characteristics. The results were used to fine tune thermal analysis and thermal management techniques.

The use of conductive epoxies was evaluated, selecting epoxies for thermal conductivity, the lift the adhesive gives to a PEM, reworkability, and the shelf and pot life of the mixed compounds.

Bonding is often necessary for thermal dissipation or vibration damping; however, it requires additional manufacturing steps that drive system cost up. Because of the additional cost, bonding should be employed only when analysis indicates it's a necessity. Board designs should contain enhanced thermal paths to reduce or eliminate the amount of epoxy/adhesive. When applying adhesive, general adhesive, generally, a matrix of dots gives better results than does either a series of lines or a solid area.

While not yet in wide spread usage, the concept of a spray cooled board proved to be an effective method depending on board population density. Spray cooling allows the use of low

cost air cooled COTs boards. It also provides an increase in heat transfer density as compared to conduction cooling or standard air cooling. The evaporation of the Flourinert spray provides a large heat capacity. This improved thermal capability provides lower device junction temperatures which can improve the device reliability. For thermally limited systems, the spray cooling can provide growth capability for additional processor boards.

Helium cooling was also evaluated and while theoretically valid, it proved to be difficult to implement. The circuit board is enclosed with a sealed cover on the module and the space filled with helium to enhance heat transfer. The thermal conductivity of helium is more than five times the conductivity of air, at temperatures typical for electronic components. This provides a better conduction path from the component to the printed circuit board and cover which are thermally connected to the heat sink, located at the edge of the printed circuit board. The concept of helium cooling is sound; however, it produces two major drawbacks. Helium cooled boards are very expensive and it is extremely difficult to achieve a seal to retain the helium.

2.3 Reliability Prediction Process Flow

The goal of CPOM reliability prediction analysis was to improve the existing reliability prediction methodology, specifically addressing commercial parts in military applications. The approach was to use field data to identify improvements in prediction modeling assumptions and to develop a standardized prediction process based on modeling enhancements, yielding credible MTBF results.

An independent assessment of field data collected on plastic parts used in a military, airborne environment was performed. Northrop Grumman then generated predictions using traditional methods (MIL-HDBK-217FN2) and alternative models (RAC PRISM®), comparing findings to field data from the MODAR program.

This exercise provided justification to modify MIL-HDBK-217FN2 factors for better correlation to field data and more accurate inputs to obsolescence management decision tools.

The RAC PRISM® tool was evaluated against new designs to serve as baseline for evaluating future prediction methods.

An improved prediction process was established utilizing a standardized methodology and sharing of component data across programs.

Results showed that MIL-HDBK-217FN2 predictions based on π_Q factors of 2 or 3 were within 10% of the demonstrated field reliability for the CCAs in the study. This observation provided the basis to use "better than" standard π_Q factors when predicting reliability for plastic components. The modified factors are contingent upon a disciplined parts selection process and proper attention to component derating practices.

PRISM® predictions correlated better to the field data when the duty cycle and cycling rate default values were modified to more closely represent the field operating conditions. On average, the predictions were 20% to 40% closer to the field data compared to the initial predictions based on the PRISM® environmental default values.

RACRates® models embedded in the PRISM® tool should be used to the maximum extent possible. Our experience revealed the failure rates from the RAC database skewed the overall prediction for one of the CCAs in the study. This observation confirmed the need for additional RACRates® models if the PRISM® tool is to become a viable method for predicting the reliability of complex systems.

PRISM® predictions produced overly optimistic results when the System Level Multiplier was incorporated in the analysis. Our recommendation is to continue generating predictions with and without the System Level Multiplier, yet refrain from formally using it until field data is available to substantiate the factors. Specific knowledge of the program's design, manufacturing, quality and management practices is required for an accurate assessment.

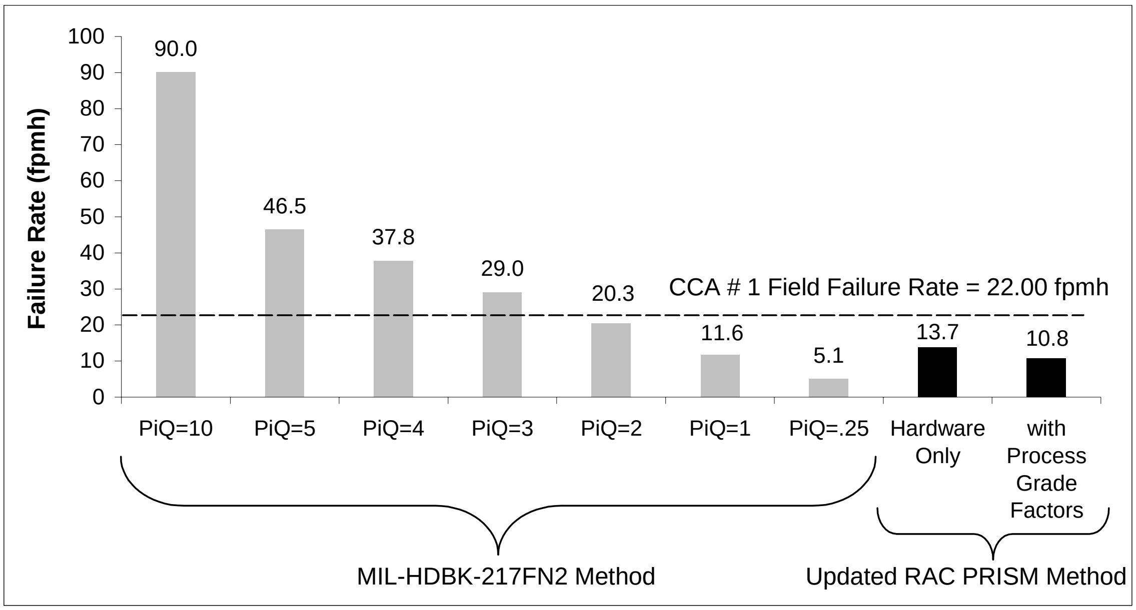


Figure 2-1 A typical Result for one of the Two CCAs in the Study

The range of data points shows how the predictions varied according to assumptions and methods.

The MIL-HDBK-217FN2 method which best correlated to the field data was based on a quality factor of 2. The PRISM® prediction which came closest to the field data was obtained after modifying the default values and excluding the effects of the System Level Multiplier (process grade factors).

2.4 IMPROVED POLICIES/PRACTICES/PROCEDURES

2.4.1 CSM Implementation (ITA)

Parametric component search and selection, a common Standard Parts List and a common new part qualification procedure were implemented using the i2 Component and Supplier Management tool. This allows for electronic collaboration at Electronic Systems sites across the country.

2.4.2 Integrate CSM to Design Tools (ITA)

The i2 New Part Request workflow was electronically integrated to the ECAD model and board layout library process. A request for a new CAD model automatically triggers a New Part Request. The part number and basic part metadata are validated prior to the generation of the CAD model. Full part qualification proceeds in parallel with the model creation.

2.4.3 E - Procurement Model (ITA)

Procurement cycle time for standard parts was reduced and designers were encouraged to use standard parts by automating the electronic procurement of these devices. SPL parts are placed on corporate contract by procurement with pricing having been prenegotiated. These parts also appear in electronic catalogs that allow designers to directly “order” the materials they need for developing designs. While not used as a production procurement system, this approach has helped to get engineers working material and increase standard part usage.

2.4.4 DMS Work Flow

i2 Life Cycle Management System (LMS) data is used many times during a program’s development. The LMS data is evaluated as a part of the New Part Request. It is evaluated again during the design review process. A Bill of Material can be analyzed by exporting the product structure from the product data management system and electronically comparing it to the i2 life cycle data. Automation of the process has been demonstrated using Titan’s Poet software suite.

2.4.5 Electronic Design Model Library (ITA)

As a means of reducing design cycle time, CPOM sponsored the creation of ECAD models for items added to the Standard Parts Lists by the Commodity Design Teams. This made the devices readily available to engineers without the need for an ECAD model request.

2.4.6 RF SPL and Qual (1/2 ITA)

The RF Commodity Design Team expanded the classic definition of PEM to extend the concepts developed for qualification of digital ICs to the RF world. Qualification requirement thresholds were developed and published. The RF Standard Parts List was released into the i2 Explore software and is available sector wide to assist designers in selection of qualified components for use in our applications. The Commodity Design Team is using the i2 Explore NPR routing and approval tool as noted above. The RF Commodity Design Team performed many technology reviews with preferred suppliers, soliciting their input into the RF SPL.

2.4.7 Design/Hardware Reuse

Reuse of design in the form of Modular Building Objects (MBOs) and Virtual Modular Building Objects (VMBOs) is proving highly successful. The intent is to reduce both cycle time and cost by increasing the reuse of existing designs.

Though the pilot focus changed due to contractual changes to the MP-RTIP program, the initial design reuse evaluation is an indication of how successful Northrop Grumman’s focus on

design reuse has become. The original MP-RTIP exciter design was evaluated just after the proposal and was demonstrated to contain 45 percent assembly reuse and approximately 70 percent component reuse based upon the Common Radar Modules design approach..

2.4.8 Software Reuse

A searchable software reuse library was developed and deployed. The library is expected to continue to grow and evolve using Northrop Grumman funds.

2.4.9 Design for Next Generation

Design for next generation has been demonstrated successfully as a part of the original Modular Building Object (MBO) approach. Design engineering was reorganized using a functional product line approach in both engineering and manufacturing. New design begins with the premise that the design will be reused across platforms and must be architected in a manner to enable upgrades and maintenance. This is documented in internal procedures and is addressed during product and program reviews.

2.4.10 Preferred Supplier Meetings

Commodity Design Teams have continued to hold SPL reviews and technology exchanges with preferred suppliers. Northrop Grumman provides the preferred suppliers with business forecasts and anticipated design needs. The preferred suppliers provide Northrop Grumman with standard parts lists recommendations, technology forecasts and technical expertise.

2.5 RECOMMENDATIONS & DESIGN GUIDELINES

As noted in the previous subparagraphs of this section, design rules and design guidelines were created and design reviews implemented to track compliance.

2.6 GEORGIA TECH SUBCONTRACT – PHYSICS OF FAILURE MODELS

Over the last decade, IC packaging technologies have evolved considerably to accommodate the advances made in the semiconductor industry. Technological advances made in the semiconductor industry have been driven primarily by the commercial market needs. Meantime, the military electronics market share by percentage of the total market has declined significantly, and is estimated to be less than 1% of the semiconductor market in the dollar sale amount. COTS components are designed and developed for the applications, which have a different set of product life requirements (i.e. long-term reliability), operating and storage environmental requirements, and criticality of the performance reliability than the military avionics applications.

The challenges associated with integrating the COTS components in the military avionics applications are two-fold: 1) the long-term reliability when subjected to the harsh environmental conditions typical of the military avionics applications, and 2) relatively rapid obsolescence of the COTS components. Some of the COTS components are robust enough so that they can be successfully used in the high performance military avionics applications. Traditionally, standard

accelerated environmental tests are performed to assess and ascertain the long-term reliability of the COTS components to utilize them in the military applications. Traditional time consuming test and qualification approach is rendering itself inefficient as the semiconductor packaging technologies are advancing rapidly to accommodate the fast evolving sub-micron semiconductor technologies. A virtual qualification approach based on physics of failure needs to be developed to manage integration and obsolescence of the COTS components in the military applications

In the Commercial Parts Obsolescence Management (CPOM) program, physics of failure based-methodology was developed to enable virtual qualification of the COTS components at the zero level (i.e. semiconductor - integrated circuit level) and at the second level of packaging (i.e. interconnect level). The physics of failure based virtual qualification of COTS components methodology was accomplished by using a three prong approach, which consisted of development and validation of electrical models, thermomechanical models, and characterization of the commonly used electronic packaging materials over a wide range of environmental conditions. The electrical models, addressing the likely failure mechanisms attributable to the failures of micron level and sub-micron level semiconductor packaging were compiled in the graphical user interface (GUI) format. The user-friendly GUI format would enable a larger engineering community in the industry to use the physics of failure based-models for virtual qualification of the COTS components. Likewise, parametric thermomechanical models, addressing the failure mechanisms attributable to the failures at the second level (i.e. an IC package-to-PWB interconnect level) packaging were compiled in the GUI format. A database of material properties of widely used electronic packaging materials over a wide range of environmental conditions was compiled such that it can be readily integrated into the commercially available analysis software tools such as ANSYS. Additionally, an alternate accelerated thermal cycling approach based on the physics of failure was proposed to optimize the duration of the accelerated environmental tests. The models also facilitate evaluation of reliability enhancement approaches such as the use of an underfill at the second level packaging.

2.6.1 Electrical Models

A wide range of digital, analog, and mixed-signal integrated circuit (IC) devices (i.e. application specific IC-ASIC, processors), incorporating sub-micron level semiconductor fabrication technologies, was reviewed to determine the associated failure mechanisms and modes. Based on the reviews, electromigration (EM, hot carrier (HC), and electro static discharge (ESD) were identified for modeling. GUI based, application specific IC reliability assessment tool (ARET), which included models for EM, HC and ESD was developed and validated.

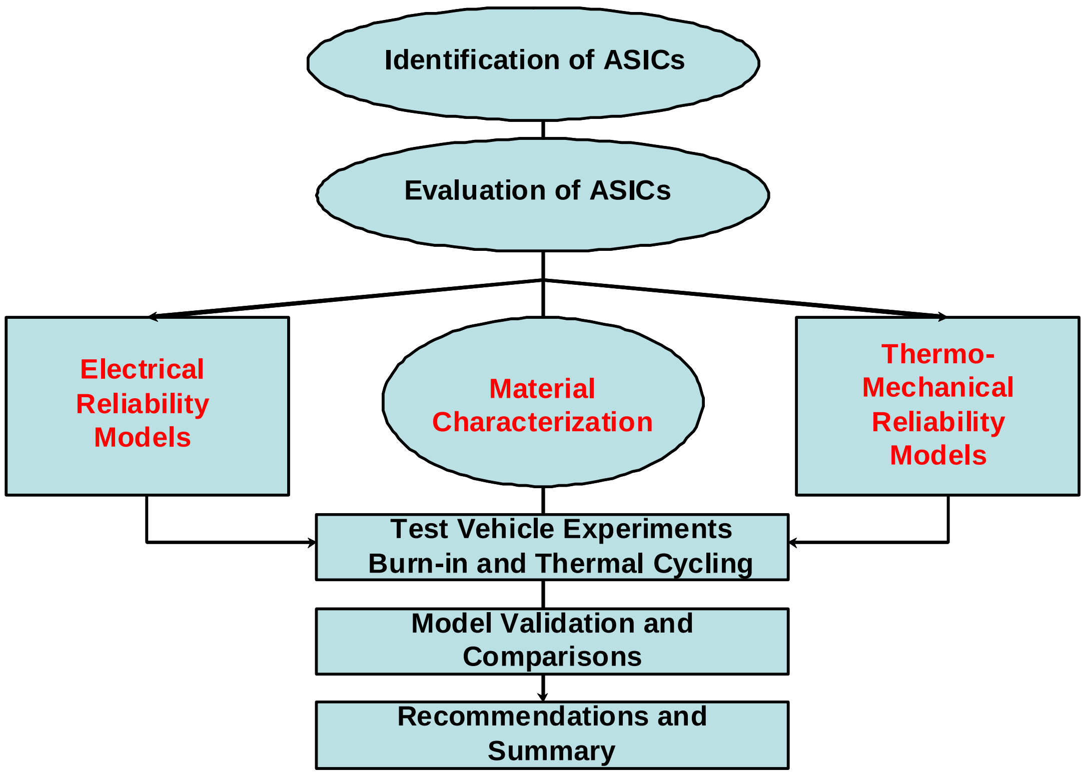


Figure 2-2 ASIC Qualification Methodology

- Developed physics of failure (POF) based reliability models for mixed signal ASICs consisting of digital as well as analog devices
- Developed methodology for determining the failure rates and expected lifetimes of commercially available mixed signal ASICs based on POF
- Developed POF based tool which includes models of failure mechanisms most likely to cause failures when the COTS devices are operated in the typical military application environment
    - o ARET
- Uses hierarchical analysis approach
    - o Behavioral models allow propagation of electrical stress factors at the circuit input to sub-modules and lower level building blocks – top down

- o Stress factor are combined with the physics of failure models to assess the performance degradation due to specific failure mechanism
- o The performance degradation is propagated bottom-up through hierarchy to assess the performance degradation and time to failure at the higher-level and the system level
- o The tool accepts net-lists from commercially available design tools such as Cadence

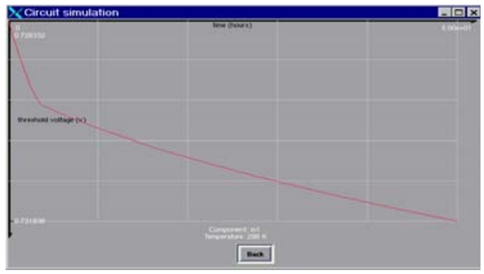


Figure 2-3 ARET Output for Hot Carrier Failure Mechanism

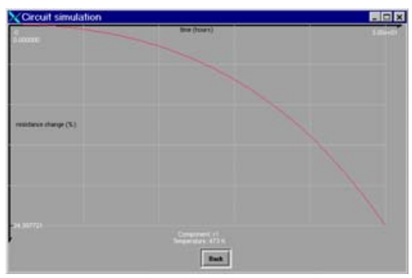


Figure 2-4 ARET Output for Electromigration Failure Mechanism

- Tool Validation
  - o Various test structures were designed, fabricated, and tested, leveraging a program at Boeing for the model validation
- AIM C5N fabrication process

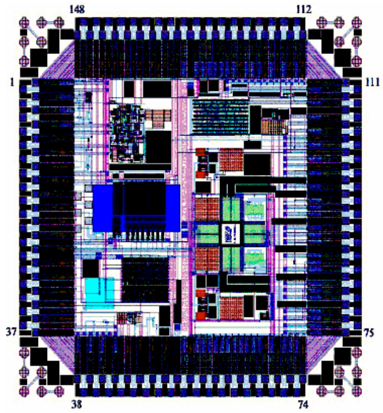


Figure 2-5 Test Structures on the die Fabricated for the Boeing Program

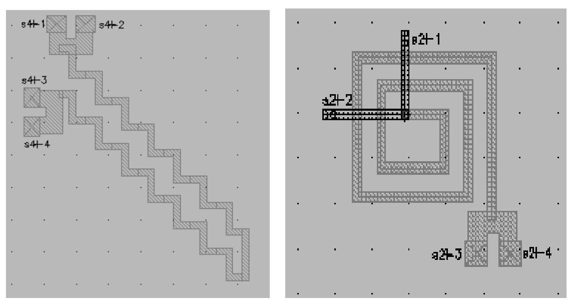


Figure 2-6 Test Structures for Electromigration

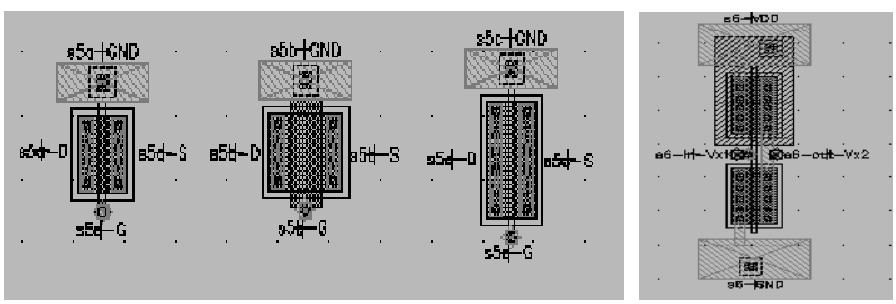


Figure 2-7 Test Structures for Hot Carrier

2.6.2 Thermomechanical Models

BGA packages, representative of the ones likely to be used in the military avionics applications, were selected after thorough literature review, inputs from engineering at Northrop Grumman Corporation, and inputs from the industry work shops for modeling and model validation. A test vehicle assembled with the selected BGA packages was subjected to accelerated environmental tests to validate the thermomechanical models.

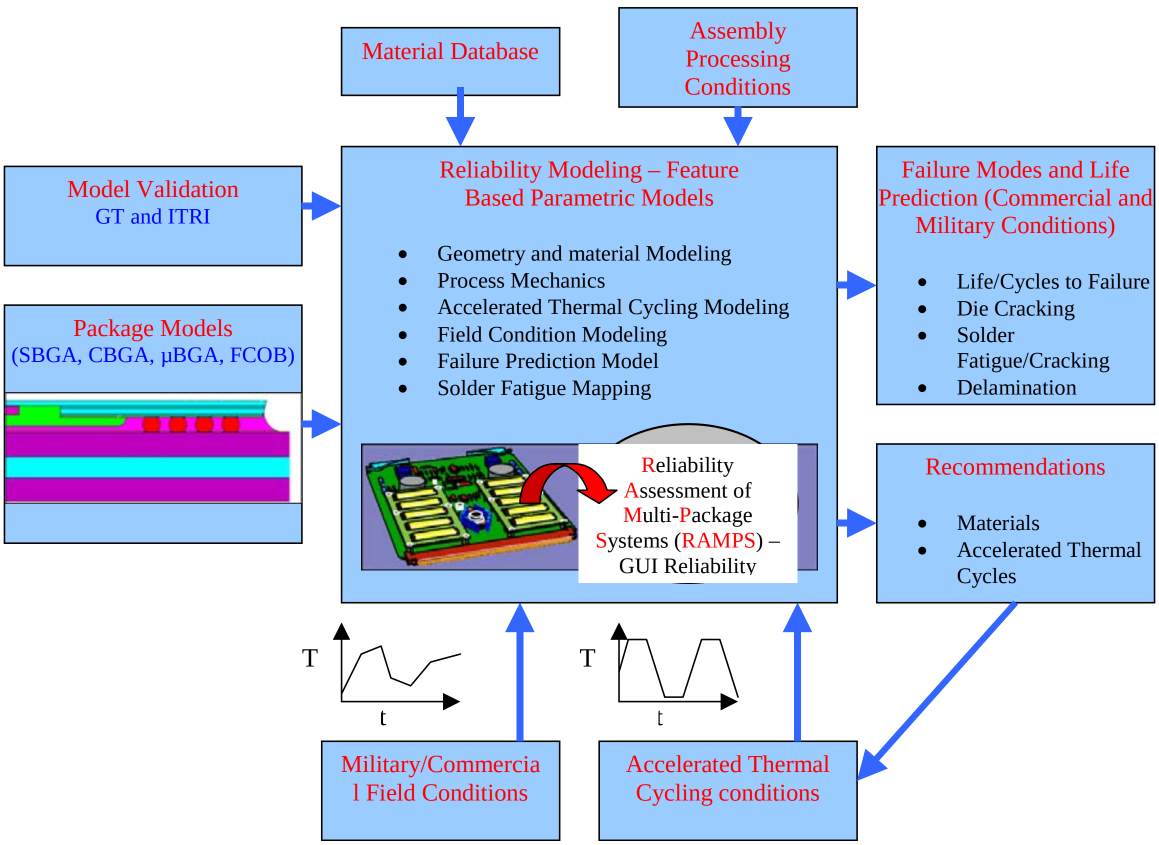


Figure 2-8 Thermomechanical Reliability Models and Tools

- Developed parametric physics of failure based reliability models for representative BGA packages and assemblies
    - The models utilize the time and temperature dependent viscoelastic and viscoplastic material behavior
  - The models allow package geometry parameters as variables

- Models facilitate assessment of solder joint reliability enhancement approaches such as use of underfill
    - Developed guidelines for selecting underfill material properties for optimal reliability of underfill IC packages
- Developed qualification guidelines for IC packages used in military field-used thermal conditions
    - An alternative accelerated thermal cycle profile representing corresponding damage that occurs in the actual field conditions was proposed to optimize the cycle time
        - Industry recommended accelerated thermal cycle may be too long and may not truly represent the damage caused in actual field life
- Developed automated post processing methodology for life prediction and user interface reliability tools for multi-package systems
    - Parametric GUI based tool allows a user to build models through graphical user interface
    - Tool allows a user to vary a number of package construction parameters
        - Package I/O pitch
        - Number of I/Os
        - Package substrate thickness and material
        - Solder sphere size
        - Package side solder sphere pad size
        - PWB side pad size
        - Solder sphere material
            - Solder sphere may be lead-free
    - Tool allows multi-package system
        - Solder joint reliability of a number of packages of varying constructions types and sizes may be evaluated in one simulation
- Model validation
    - Validated the solder joint reliability assessment from models with the test data
        - A test vehicle designed, fabricated, and assembled at Northrop Grumman Corporation was tested under accelerated thermal cycle tests for over 4000 thermal cycles

2.6.3 Characterization of Electronic Materials

In electronic packaging, materials varying in material properties and dimensions by multiple orders of magnitude form interfaces. It is critically important that commonly used materials in COTS components be characterized over the environmental conditions typical of military avionics applications.

- Multiple interfaces were characterized over a wide temperature range and material properties were determined
  - Metal-metal-metal interface
  - Organic printed wiring board (PWB) material-metal trace-solder mask interface
- Multiple interfaces were characterized to determine the effect of crack-tip plastic deformation on the interfacial fracture toughness through a four point bending test
  - alumina-underfill interface
- Underfill material characterization
- Fracture toughness evaluation of several interfaces
  - Underfill-polyimide
  - Underfill-aluminum
  - Underfill-FR4
- Effect of surface roughness on interfacial
  - Aluminum-FR4 epoxy
- Effect of moisture on interfacial fracture toughness
  - Underfill A – FR4 substrate
  - Underfill B – FR4 substrate
- Material Properties Database
  - A database of material properties of commonly used electronic packaging materials was developed – properties were either determined experimentally, or collected from literature
    - Semiconductor materials
      - Polycrystalline Silicon
      - Single crystalline Silicon
      - Polycrystalline Gallium Arsenide

- Eutectic Solder (63Sn/37Pb)
- Eutectic Solder (62Sn/36Pb/2Ag)
- Eutectic Solder (60Sn/40Pb)
- Eutectic Solder (70Sn/30Pb)
- High Temp Solder (5Sn/95Pb)
- Lead-Free Solder (96.5Sn/3.5Pb)
- Underfill/Encapsulant
    - HYSOL® CNB832-20
    - HYSOL® FP4530
    - Loctite®3564
    - Loctite®3565
    - Loctite®3568
    - Alpha EL18-LS-509110
- Organic PWB materials
    - Nelco N4000-2
    - IPC 4102/21 (FR4)
    - NEMA FR-4 Glass Epoxy
    - Thermount®

2.7 PILOT PROGRAM

In 1Q02, Northrop Grumman embarked upon a selection process to find the program that would be the best match for the CPOM Pilot. The selection process was documented and the MP-RTIP Exciter design was selected and AFRL concurrence received. The pilot also included a separate RADSS effort on APG68 Block 30/40, a MOCA evaluation and a DVTG evaluation.

The MP-RTIP SPO concurred and the pilot was started in 2Q02.

In January 2003, MP-RTIP implemented ECP 01, changing the type of aircraft using the radar and almost doubling the antenna area. Transmitter power was increased and reflected noise was increased. As a result, a lower noise Exciter was needed and the in process design had to be restarted. In addition, the MP-RTIP schedule slipped to the point that it no longer provided a good match to the CPOM period of performance.

The RADSS effort on Block 30/40 was not affected nor were the MOCA evaluation or the DVTG evaluation.

With the situation changed so dramatically, a new approach to documenting the cost avoidance resulting from the implementation of obsolescence management tools, reliability tools, corporate initiative tools and lean corporate practices was proposed and accepted. The CPOM pilot focused on collecting tool and process metrics across multiple active programs. Reports were formatted to annualize cost savings by tool or by process. In many ways this retargeting of the pilot program benefited the overall program as there was a higher volume of data to evaluate and program specific schedule dependencies were eliminated.

2.7.1 PEM Issues, Packaging Issues, Design of the Environment

The objective of this task was to measure the cost and schedule impact of PEM issues, Packaging issues and Design of the Environment activities undertaken in the ACME portion of the program.

PEM selection criteria, Packaging, handling and Design of the Environment data has been incorporated into Northrop Grumman Integrated Enterprise Process work instruction E24110. This is the guiding procedure for Commodity Design Team day to day activities.

The leading edge microcircuit technologies currently available as Plastic Encapsulated Microcircuits represent a significant increase in device capability. When properly selected, they also represent a significant decrease in material cost when compared to similar hermetic devices. For high pin count devices, the hermetic package itself can cost around $100.

In their paper "Plastic-Encapsulated Microcircuit Reliability & Cost Effectiveness Study", D. Emerson, E. Hakim, and A. Govind derived a cost comparison between hermetic integrated circuits and plastic encapsulated microcircuits that indicates an average 6-fold decrease in material cost when commercial devices are used. This is much more apparent with the lower pin count devices as the package dominates the material cost. As pin count rises, the integrated circuit chip cost dominants and the cost ratio decreases; however, many of the large scale integrated circuits are available only in the PEM format. Earlier Northrop Grumman analysis indicated that a four to one ratio is more appropriate when accounting for the internal costs associated with qualification and handling of COTs and represented a conservative estimate of the cost impact of PEM.

Similar analyses for industrial versus military passive devices have yielded mixed results. JPL's COTSCON presentation concluded that "commercial" resistor arrays cost them more than twice as much to process than their equivalent military devices. Given those results and the relatively low cost of the discrete passive devices, that analysis is omitted.

Analysis indicates that disallowing the use of COTs in the MRPTIP exciter design would have a material cost of approximately **$20K per system** based on the difference in pricing between hermetic and non hermetic parts.

A lead time comparison for parts planned for the MP-RTIP program was also performed. 55% of the PEM planned for MP-RTIP are not available in hermetic packages and a lead time comparison is not germane. Disallowing their use would have required the use of hermetic hybrid modules. For the parts that are available in both hermetic and plastic packages, the lead time for PEM averaged 4.1 weeks and the lead time for the hermetic packaged microcircuits averaged 8.3 weeks. **The additional delivery time for the hermetic devices is not significant**

in terms of system hardware delivery and is easily addressed through material requirements planning.

A much larger cost impact can be derived by looking at the parts in the design for which hermetic equivalents don't exist. It's logical to conclude that disallowing the unsealed microcircuits would lead to the use of hermetic multichip modules. A ballpark estimate on design cost for a complex hermetic module is that it takes seven months to do the first design turn and five months to do the second design turn. It's rare to stabilize a final design without at least two design turns. Total cost for such a module would be in the range of $1.5M as compared with the industry model of $700K for a board. If we assume that the 4.5 reused boards in the original proposal couldn't be used the redesign cost would be approximately **$3.1M**. If we assume that PEM aren't allowed and we have to design hermetic hybrids, we most likely create additional integration and replace 4.5 boards with 3 hybrid modules at a cost of approximately **$4.5M**. The time required for the hybrid redesign is approximately 1 year assuming that all modules proceed in parallel. This design cycle time isn't significantly different from the board design time.

In some cases environmental requirements preclude the use of PEM without additional design of the environment. The most typical of these is a thermal environment such that junction temperatures cannot be adequately controlled. The work done on CPOM helped to define improved thermal management practices and to increase awareness of the issue. Design rules have been enhanced and incorporated into design review practices. A thermal analysis is performed for each design and the results are reviewed by reliability engineering. Problem areas are identified. The solution may be as simple as a design iteration changing part selection. Approximately 50% of PEM applications in harsh environment require extraordinary design of environment approaches.

2.7.2 Tool Development and Evaluation

2.7.2.1 RADSS - APG-68 Block 30 Evaluation

Northrop Grumman selected the F-16 AN/APG-68 Radar Programmable Signal Processor (PSP) as the pilot program to execute and evaluate RADSS. The PSP contains 27 unique Circuit Card Assemblies (CCAs) with upwards of 100 obsolete microcircuit part types. Because of the extreme degree of AN/APG-68 PSP obsolescence and the high cost to resolve, NGC has been no-bidding RFQs for spare hardware. Northrop Grumman installed the RADSS tool, defined and developed a DMS decision model, collected data and ran analysis of tool capabilities and weaknesses.

Seven separate analysis scenarios were used to exercise the RADSS tool. The following are examples of those analyses.

Scenario #1

- RADSS choose the alternatives with the highest benefit/cost ratio.
- No constraints
- Solution set contained an alternative for all 27 CCA styles regardless of profitability

Scenario #2

- Solution set to only contain profitable alternatives from scenario #1
- Constrained on profit. Excluded all alternatives with a NPV < or = 0
- Solution contained an alternative for 14 of the 27 CCA styles.

Scenario #3

- Solution set to contain only profitable alternatives
- Constrained on fiscal DMS budget
- RADSS dropped CCA 9 and 19 from the solution set to climb under the fiscal DMS budget constraint

Scenario #4

- Solution set to only contain profitable alternatives
- Constrained on resources. Maximum of 4200 engineering hours
- RADSS excluded CCA 19 from the solution set to meet the manpower constraint
- Keep recently hired Engineers busy
- Constrained on 4200 - 9000 engineering hours
- Constrained on fiscal DMS budget
- Solution contained 8 CCAs

The pilot demonstrated multiple business cases for profitability on otherwise obsolete designs, producing a win win situation for NGC and the Air Force. The analyses showed that RADSS is a powerful decision support tool that is best used on complex obsolescence sets. It allows the user to make decisions based on decision criteria established by the organization and to make "what if" adjustments to the data to optimize the ultimate decision. Due to the complicated setup and model definition, the tool is not well suited for small scale obsolescence decision modeling.

2.7.2.2 i2 LCM – Task: Evaluate ASPECT/i2 LCM Tool

LCM (version 5.0) AFRL BAA 97-11-MLKT is currently available on the commercial market as a production product; however, it requires a significant software system upgrade (SRM) in order to implement. Northrop Grumman has negotiated a license agreement with i2 that allows the use of the i2 products across all sector sites.

Northrop Grumman Electronic Systems migrated additional data from the Rolling Meadows and Woodland Hills sites, installed the software and trained users. This is a first time installation of the tool at Woodland Hills and an upgrade of the capabilities at Rolling Meadows.

Utilizing the eDesign version of i2's software, the life cycle management data has been fully integrated into day to day component and bill of material analysis activities across the sector. Due to some issues with the i2 software, direct oracle joins to the LCM data were used as a means of accelerating the analyses and automating portions of the process. In addition, i2's LCM data and critical parameters from their commercial catalog data were integrated into the Bill of Material analysis activity utilizing Titan's Poet software.

Northrop Grumman and Lockheed Martin and BAE continue to engage in i2 data discussions as active members of the i2 users group. **This intercorporate teaming drove i2 to correct data discrepancies and algorithm differences between LCM and the original Tactrac database**. i2 announced completion of this database synchronization activity at the User Group meeting in October 03. This removes a major obstacle allowing OEMs to implement the SRM tool as it was originally intended.

Northrop Grumman utilizes i2 LCM in all stages of emerging designs: Proposal, Design, Manufacturing, Sustainment, Redesign, MOCA evaluation, RADSS evaluation, day to day parts selection and Common Product Team design activities. It is integral to the business and has very wide exposure. Common new part selection and qualification procedures were agreed upon and workflows updated to include former Litton sites.

Listing of programs impacted in 2003 based on data exports from the i2 tool.

Advanced Technology Transmitter	Agile Beam Radar
ALQ-131	APG-68 V(X)M
ASDS	ASPJ
AWACS	Block V
B1B	BAT
Comanche	DUS&T
ELMO	F15K
F-22 Falcon Edge	Flat Bed Sorter
ICAP	IFTS
Joint Strike Fighter	Longbow Missile
Longbow Fire Control	LR100
Manifest	Modar
MSTRS	PDF Lot 2
Pod Radar	RTIP
SBIRS	SBR
SPQ9B	TPS-70 Solid-State

2.7.2.3 DVTG/VectorGen Evaluation

Developed a Rosetta model for a Northrop Grumman frequency synthesizer module and used the model as an input to the DVTG/VectorGen tool, successfully generating accurate test vectors.

First, a few definitions.

Rosetta is an emerging high-level description language for specifying systems that explicitly provides:

- Support for domain specific modeling
- Support for modeling cross domain interactions
- Support for defining and combining models of systems and system components
- Support for modeling and analysis at high levels of abstraction
- Support for specifying constraints and performance requirements for the system and system components in a top-down manner
- Support for requirement verification as
- A *facet* is a model representing one perspective of a system
  - One particular point of view

– One particular abstraction level

- A *domain* is a semantic system for defining facets
- A *system* is described by:
  - Defining and composing its various facets
  - Defining and composing its various sub the system description evolves

The approach was to describe the frequency synthesizer using multiple, interacting models and then combine the models into a single functional description from which test vectors could be electronically generated. This simplified the development of the Rosetta code and made individual models easier to understand and to test.

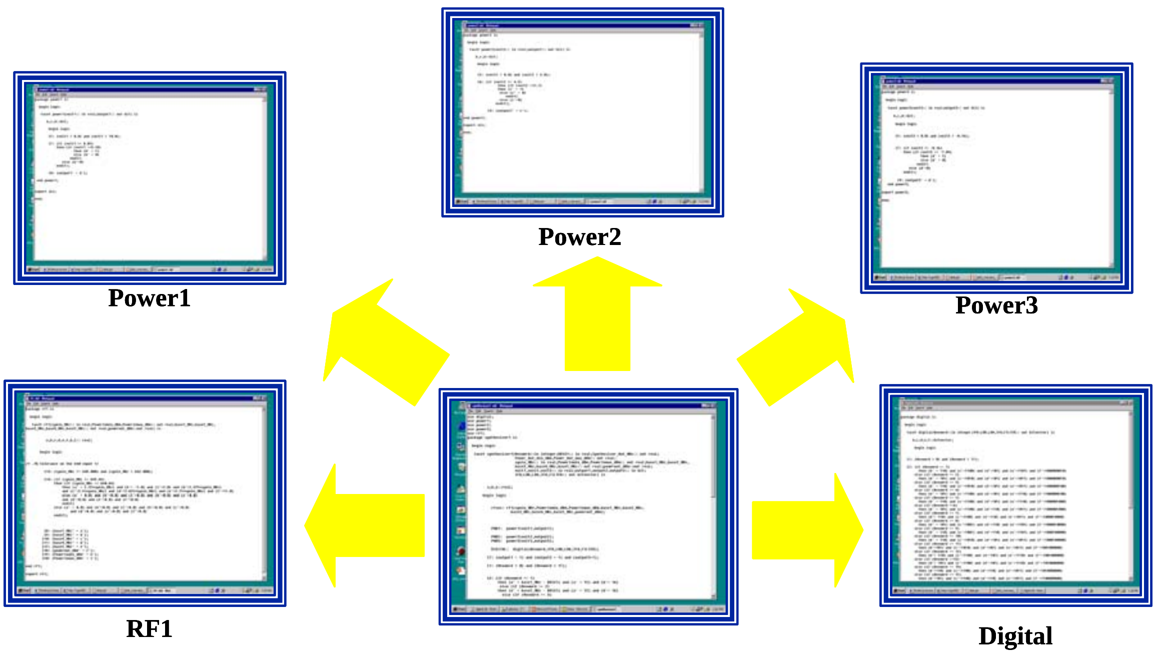


Figure 2-9 Synthesizer Parent Program

Conclusions

Rosetta

Rosetta succinctly captured the functional perspectives of the FPGA, RF and Power models of the Synthesizer and language similarities made Rosetta easy to grasp. Rosetta is in need of an Operational Subset. In its present form, it is quite adequate for design capture; however, it doesn't permit execution of code that might be needed for debugging or other purposes. An operational subset would permit execution by allowing Rosetta specification language to be interpreted as a set of instructions that can be interpreted as a program the same

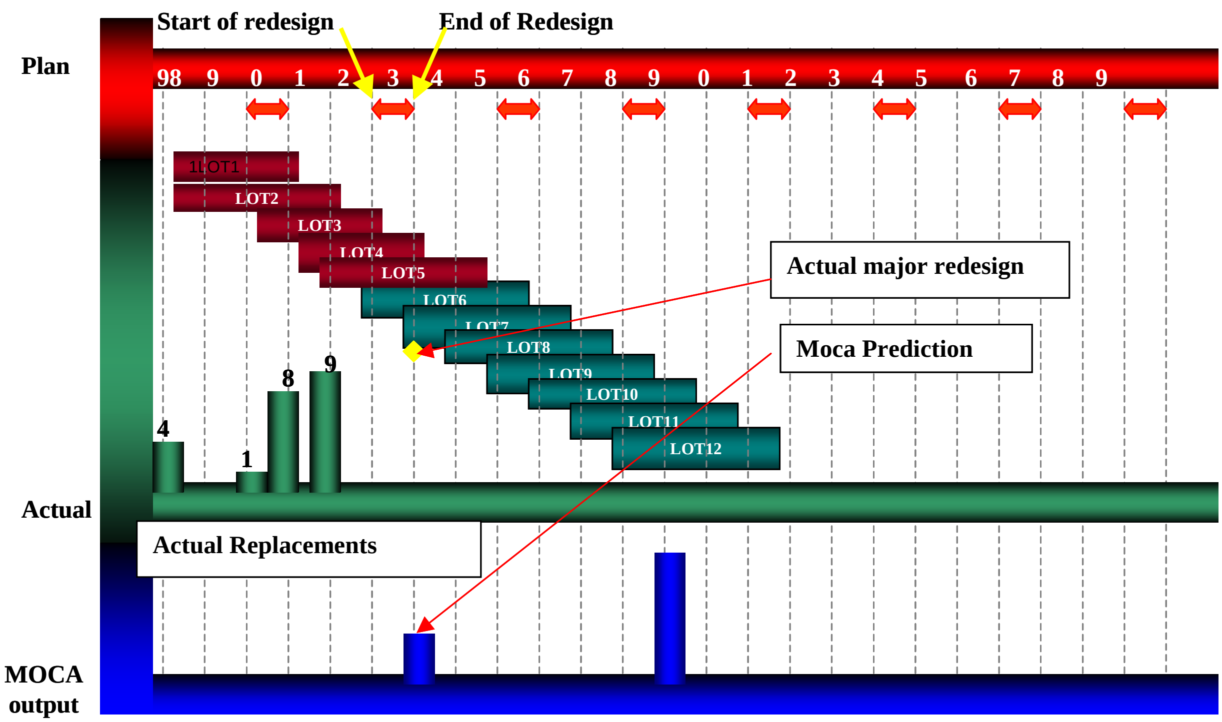
way as C or Haskell. The Interpreter would also have to be developed to evaluate expressions and produce values for input parameters

VectorGen Tool

VectorGen was able to verify models with correct output data. The tool was straight forward and easy to navigate. In its present iteration, VectorGen doesn't handle nested models.

2.7.2.4 MOCA Evaluation Pilot Loaded program data from a sustainment program into MOCA to effectively turn back the clock and compare the MOCA predictions to known occurrences.

- 5 years of Obsolescence Management Data
- Tactech predictive data
- Historical DMS notices
- Obsolescence mitigation actions



The pilot program ran MOCA as if it were 1998

- Compared results to observed actuals

Northrop Planned Redesign Activity

- Planned program life was assumed to be 20 years
- Quarterly DMS analyses were performed
- DMS issues were addressed to reach the next redesign
- A three year redesign schedule was chosen

Actual Redesign History Major redesign was later than planned

- Production was low and funding was limited

- Parts buys or alternate parts were desired to avoid redesigns
  - 2000: 1 alternate part
  - 2001: 7 parts buys and 1 alternate part
  - 2002: 9 parts buys
- Parts buys were only allowed out to Lot 3
- Qualification activities also negated unnecessary redesigns
- Contract essentially forces 1 year look ahead
- MOCA indicates a 3.5 year look ahead is optimal

Obsolescence Comparisons. Having reviewed the data from the sustainment program, we were able to provide an assessment of the DMS predictive data tools as well.

- TacTech and CALCE are pessimistic
- The dataset consisted of 95 parts
- Correlation is poor
  - CALCE is driven by technology
- MOCA needs accurate data

MOCA Assessment

- Integration to POET and PRICE works well
- MOCA output looked reasonable despite data limitations
  - However
  - Contract funding drives actuals
  - To maximize benefit of MOCA, contracts should better recognize and fund obsolescence mitigation
  - Data sources are too pessimistic
- MOCA display is clear

- Detail reporting could be improved

- Organizes a refresh plan in a manner consistent with life cycle cost
- UMD has developed a unique tool with significant potential to impact life cycle costs

2.7.2.5 Poet/Workflow Demonstration

This was a multi part task that began with the evaluation of the Rosetta language, continued through the development of the Poet software suite and finished with a live demonstration of a Poet interactive workflow interfacing with multiple design tools and data sources.

Rosetta

Rosetta models were created to represent the mathematical results of the investigations performed for Physics of Failure modeling. These models are also appropriate for use in writing and verifying systems specifications in the areas covered by the models. Titan Systems Corporation personnel coordinated with the Northrop Grumman investigation team conducting the analyses to be modeled in SLDL. The SLDL models present the results produced by the investigations in a manner that will enable systems designers to specify their designs with strict constraints on the factors controlling the success of including commercial dies, designs, and parts on military substrates. SLDL models completed as a part of this effort included: Corrosion model based on the Peck model, Stress failure model based on the Coffin-Manson model for predicting end of life due to thermal stresses, Mean Time Between Failure Model (MTBF) using the RAC model augmented with physics of failure techniques and field reliability data to electronically track changes that might impact reliability, Cooling Schema Model permitting the specification of levels of convection and conduction cooling, both for "cavity up" and "cavity down" BGA packages, Dendritic Growth model to capture the mathematical representation of the dendritic growth between fine pitch mounting pads for printed wiring boards, Thermal Expansion Model for design rule checking of electronic Bills of Materials for potential thermal mismatch and an Intellectual Property Model to demonstrate the capture of module level design and test vector generation data utilizing the Rosetta language.

Proved out Rosetta in the context of both design and requirements. Proved Rosetta was easy to learn and use by new designers not familiar with system level languages. Demonstrated the feasibility of using Rosetta models in combination with Poet for the automation of design rules checking

All of the above benefits served to provide constructive feedback to the Rosetta development community in order that future language and tool development would be sure to incorporate lessons learned from CPOM experience, thus making the language and tools more usable and, in turn, more commercially viable.

Poet Development

The primary focus of Titan during the CPOM program was the development of Poet. Poet is a software tool that enables designers to efficiently manage data, tools, design rules checks (DRCs), and processes in a centralized and coherent manner. With regard to the objectives of

CPOM, Poet provides a commercially viable solution to facilitate the redesign of obsolete assemblies by:

- Enabling process management via workflow
- Providing information management
- Providing product management (design data and design validation and verification)
- Enabling tool invocation
- Providing an intuitive, web-enabled interface

Titan was able to draft initial requirements, design, develop and test Poet during the CPOM program. The testing was completed by installing Poet at a Northrop Grumman facility and by processing design data from a real Northrop Grumman assembly. Afterward, a series of demonstrations was presented to both Northrop Grumman and the Air Force to verify that Poet was indeed working as described. Some of the features presented at the demonstrations includes.

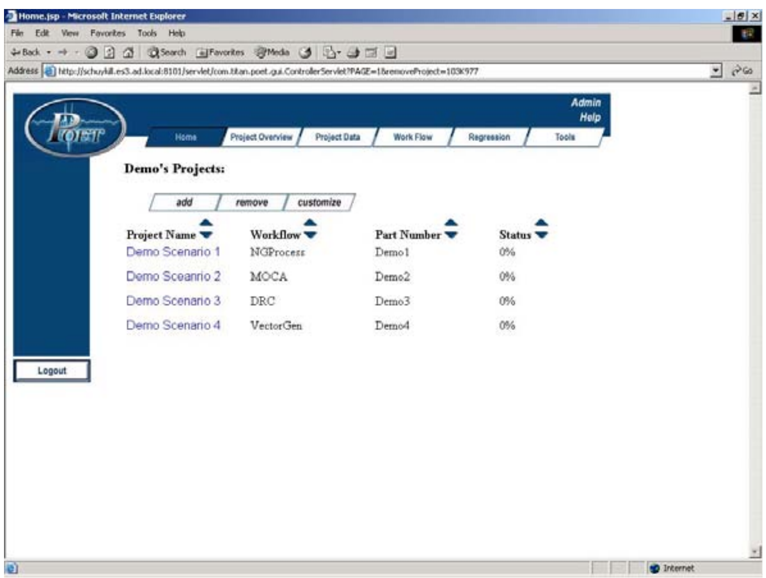


Figure 2-10 A Summary View of Multiple Projects

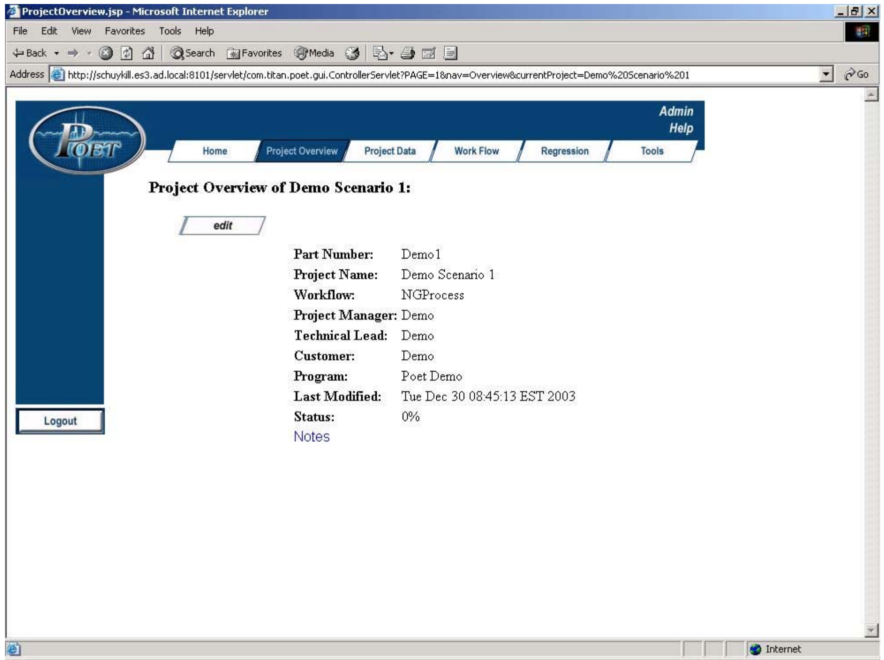


Figure 2-11 An Overview for a Single Project

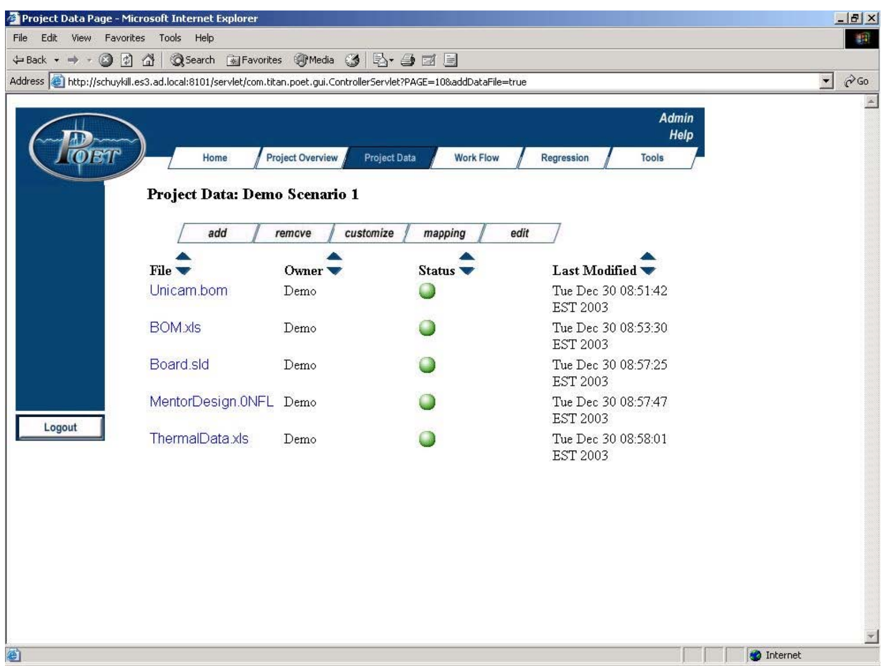


Figure 2-12 Data Files That Constitute the Project

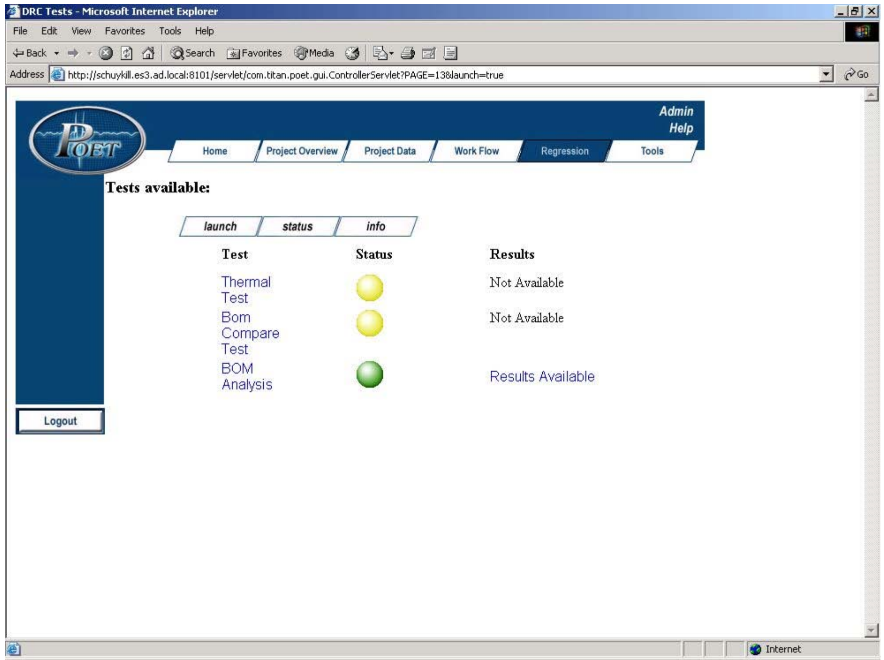


Figure 2-13 Design Rule Checks to be Run Against Project Data

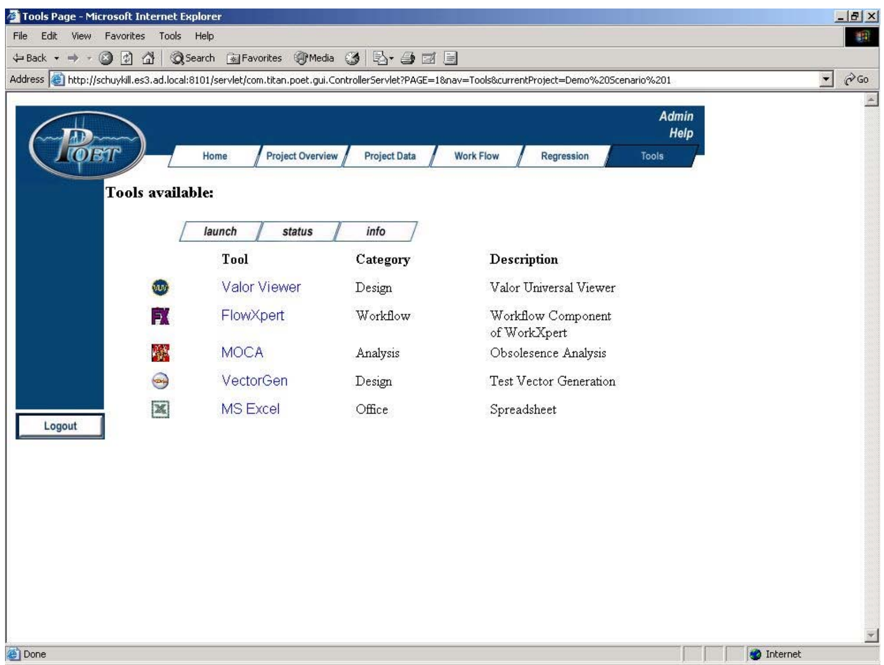


Figure 2-14 Tools to be Used to Accomplish Project Tasks

Benefits Realized

Many benefits have been realized through the development of Poet. Some of the highlights include

- Integrating heterogeneous design information and tools
- Managing the information flow through a design process
- Promoting collaboration and insight throughout design process
- Providing the ability to validate and verify new design form, fit, and function against legacy design
- Facilitating repeatability in design process
- Providing auditable process conformance (CMMI)
- Providing, through use of Rosetta, consistent method for design capture

Driving the Design Process Using Poet

To assess the commercial viability of Poet, Titan undertook a follow-on task to demonstrate how Poet, in conjunction with a commercially available workflow tool (Mentor's WorkXpert), could be applied to drive a real world design process at Northrop Grumman. The project was defined to address four key elements in driving a process:

1. **Define and implement a design process using the workflow tool.** For this task, an established Northrop Grumman design process would be captured using the workflow tool. One of the steps of the process, BOM Analysis, would serve as a test case for automating a process step. A bi-directional interface between the workflow tool and Poet would need to be established to facilitate the brokering of information between the two.
2. **Automate BOM Comparison and Analysis.** Poet would be used to resolve the differences among multiple Bill Of Material sources that include CAD design data, components databases, and web-enabled interfaces to databases. The analysis would consist of twenty-five tests that ranged from determining critical lead times to identifying components with Diminishing Manufacturing Source (DMS) issues.
3. **Collection of Cross Project Metrics.** Poet would be used to collect predefined metrics from the workflow tool. The workflow tool itself is capable of only reporting on a single design project at a time. Poet was to provide the added power of being able to pull data from multiple projects into a single reporting mechanism, thus enabling a designer or manager the ability to view a snapshot of the status of all projects in a single report.
4. **Centralize project tracking**. A web-based producibility checklist was used**.** The purpose of this task was to take an Excel spreadsheet that was used for project tracking purposes and to web-enable it in a manner that allowed users access to, and modify as necessary, its information without creating a need to pass around multiple copies of the spreadsheet.

Accomplishments

The Northrop Grumman and Titan team was able to meet the goals of demonstrating capabilities to drive processes by Defining and implementing a design process workflow using the Mentor WorkXpert tool. Automating a step of the workflow, BOM Comparison and Analysis, using a standard test interface that could be employed in the development of additional automated analyses. Twenty-five different BOM Analysis tests using four different BOM data sources were implemented. Gathering and reporting of eight key project metrics from the WorkXpert workflow. Developing and implementing a web-based tool for project tracking that assumes the role previously held by an Excel spreadsheet. These four tasks (workflow development, BOM analysis, cross-program metrics reporting, and producibility checklist) provide key elements necessary to drive processes in a repeatable manner.

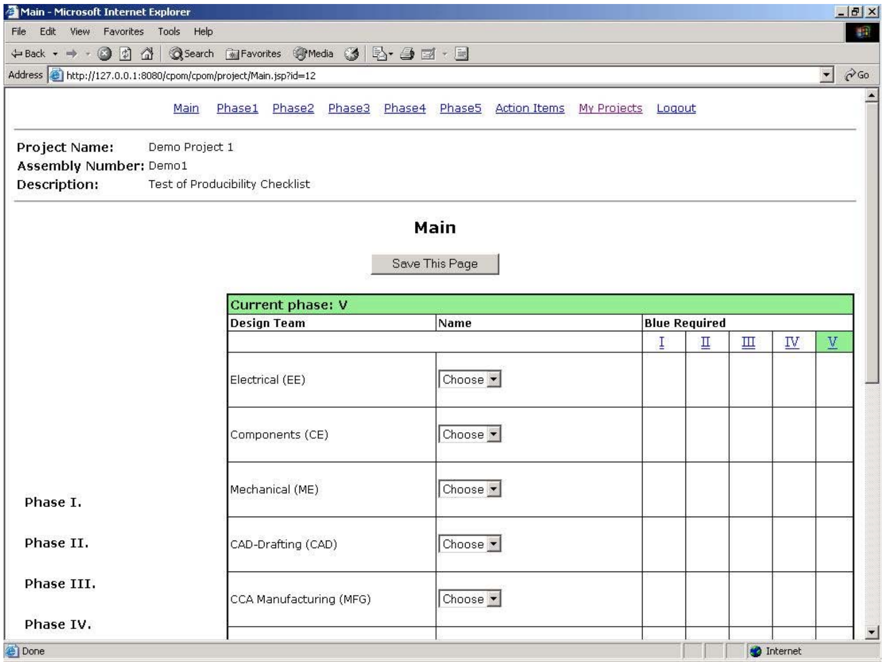


Figure 2-15 Producibility Checklist Main Page

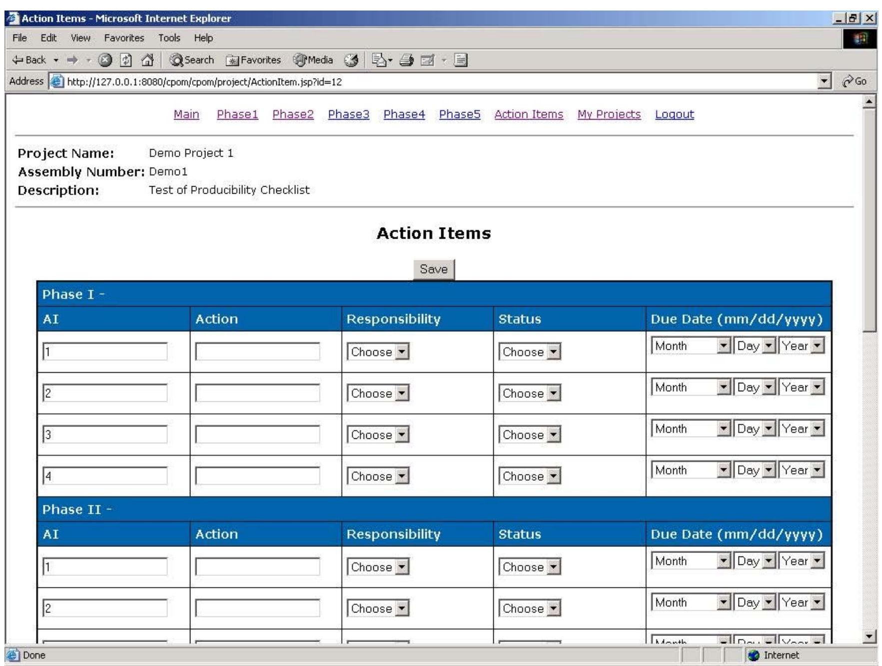


Figure 2-16 Producibility Checklist Automated Action Items

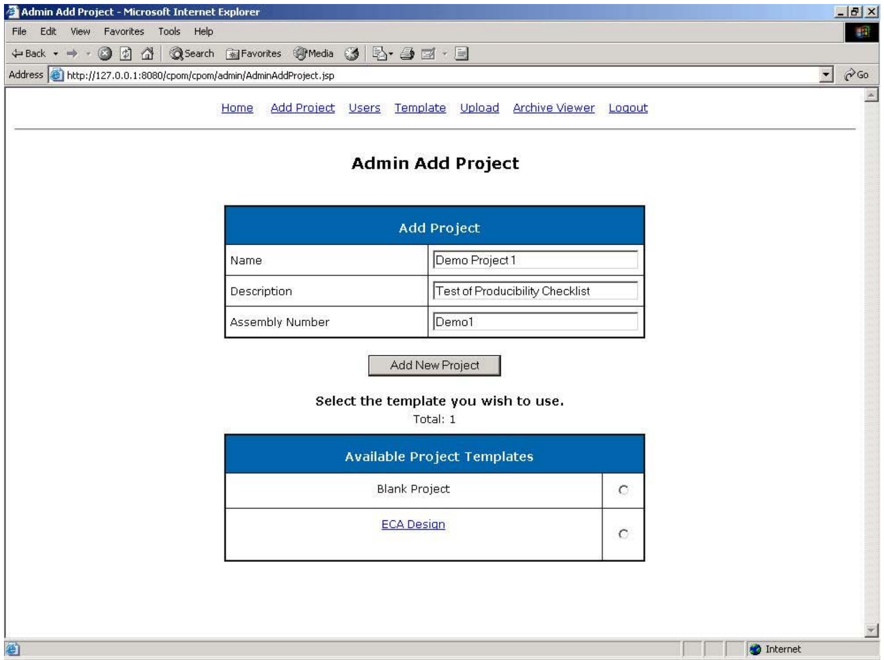


Figure 2-17 Admin Page Project Control

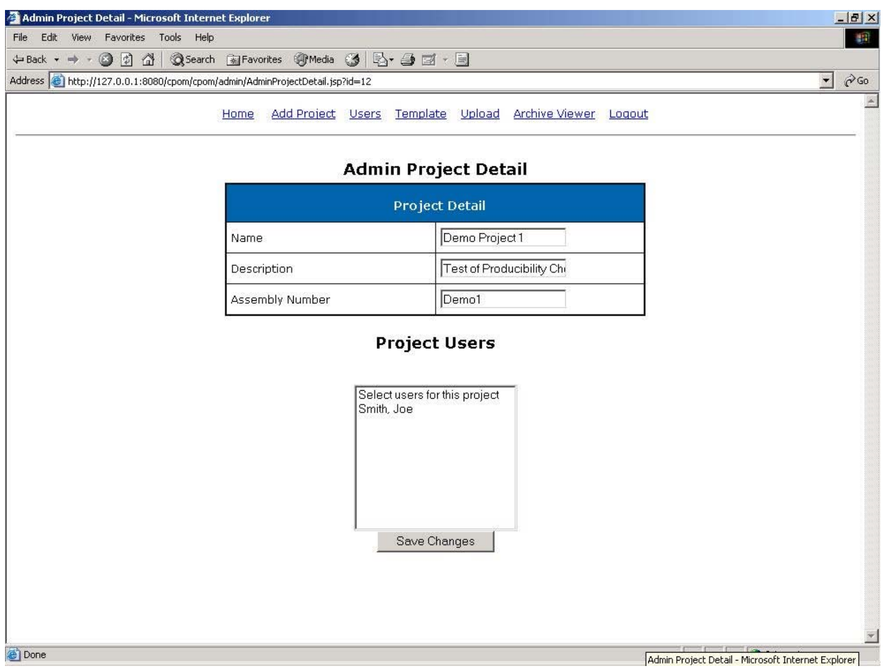


Figure 2-18 Admin Page Users Control

The Producibility Checklist provides a centralized mechanism for tracking project status by providing features such as (from upper left) facilitating signoffs across all phases of the design cycle, capturing and tracking action items, managing user access and capabilities for individual users, and managing the creation and archiving of individual projects.

Benefits Realized

The key benefit achieved by the combination of the four task areas is a capability to drive processes in a consistent and repeatable manner. This benefit is achieved as a result of the combination of benefits achieved for each of the individual tasks. These benefits include:

Workflow Implementation

- Documentation of process
- Repeatability of process
- Automation of process steps where appropriate
- Ability to track project based on tangible metrics

BOM Analysis

- BOM analysis is automated
- BOM analysis is repeatable
- BOM discrepancies caught earlier in the process, thus avoiding costly rework
- Recurring engineering functions have been reduced to a single NRE cost
- Test data preserved and maintained
- Tests are developed through a common interface that speeds development of new analyses tests

Metrics Capture

- Centralized metrics report
- Metrics based on measurable state of workflow
- Metrics capture across programs and not just for a single oneReduces configuration challenges of maintaining a single spreadsheet amongst the entire design team
- Provides access to producibility checklist to entire design team, as well as managers and others with vested interest in project status
- Extensible to include additional features

Conclusion

Titan has been able to develop a commercially viable services offering based on the development of Poet and its capabilities for driving processes as previously described. This commercial viability is demonstrated in the ongoing discussions between Northrop Grumman and Titan to further institutionalize the results of the CPOM program at Northrop Grumman. As the development of a commercially viable offering was a key objective for Poet in the CPOM program, the program itself can be considered a success in achieving this objective.

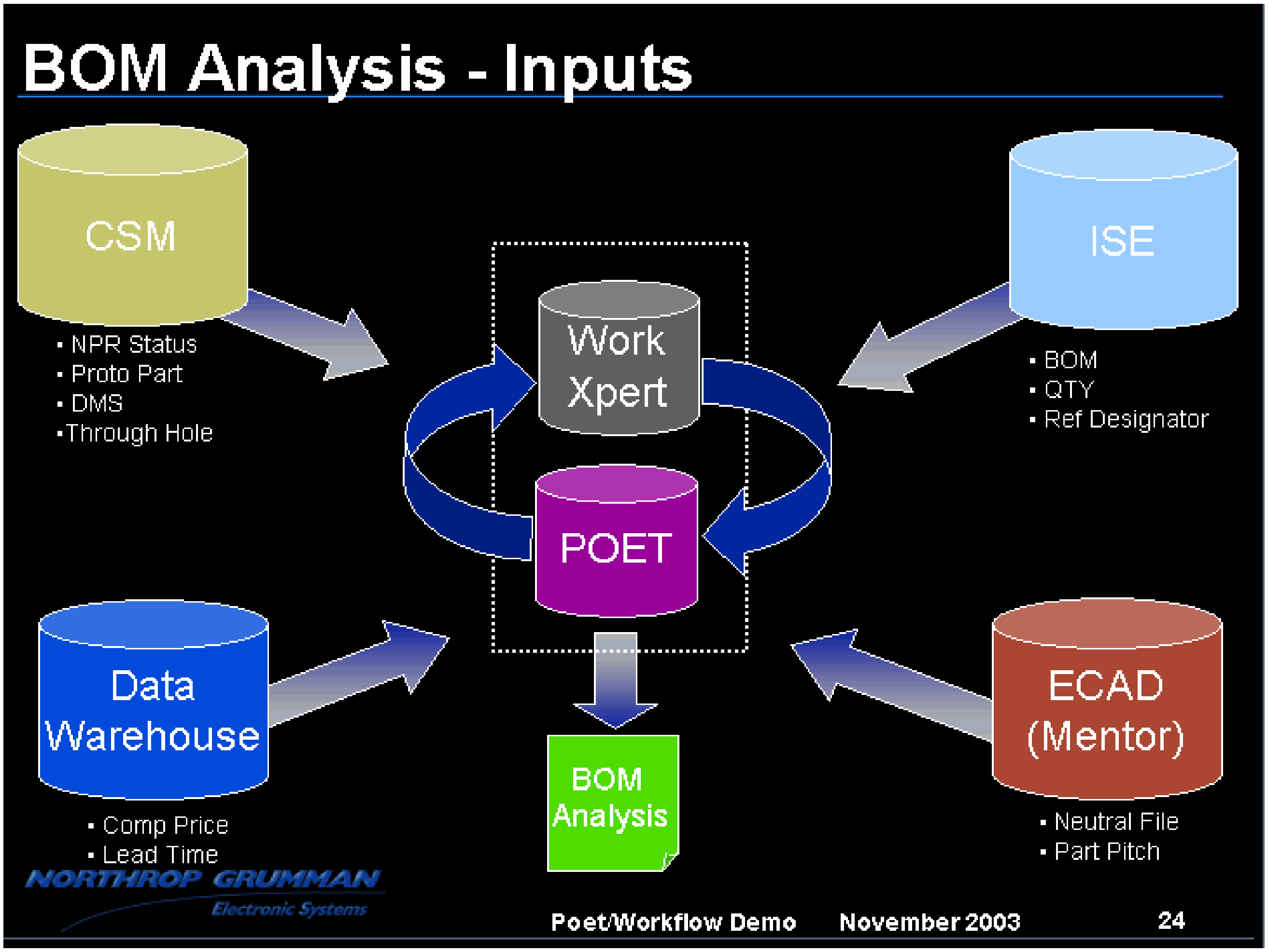


Figure 2-19 Bill of Material Analysis Automated using Poet and WorkXpert

2.7 Improved Policies, Practices, and Procedures

Common Product Teams established design rules, value stream mapped design processes and established a detailed design review process resulting in ECA cycle time quotes down 23.5% (~175 designs), MCM cycle time quotes down 12 % (~ 15 designs) with Structural system design cycle time quotes steady. With some simplifying assumptions this translated into ~$11M/year CPT design cycle time reductions

Commodity Design Teams. Commodity Design Teams processed 6855 New Part Requests in 2003 using the i2 workflow and supporting data. Of those, 6027 were evaluated and approved as submitted, 722 were rejected and replaced with existing or standard component selections (722 x $9400 = $6.8M), 4624 part numbers revised or corrected. ($1.86M/yr in revision notice avoidance) totaling ~ $8.7M/year across 23 major program developments.

Enhanced reliability modeling. Reliability prediction procedures updated to reflect tool and field data evaluations.

Documented >$22M annual cost reduction from processes and tools

Improved thermal design rules implemented with a few modeled and electronically automated using the Poet software.

Improved material handling through electronic automation of data flow between the PDM system and the manufacturing floor. Material handling codes developed and implemented to display shelf life, moisture sensitivity, packaging for manufacturability. Data is input through the New Part Review process, evaluated through the design review process and displayed on the manufacturing Bill of Material.

Improved manufacturability through incorporation of manufacturing rules, lessons learned and packaging requirements in the New Part Review and Design Review processes.

Enabled COTS technologies by establishing qualification thresholds and thermal management processes.

Ledger stocking program. Established inventory stocking procedure that links Standard Parts Lists and high use components to ledger stores.

Supplier Managed Inventory Program. Commodity Design Teams, procurement data and i2 data used to establish a supplier managed floor stocking program for high use, low cost components thereby reducing procurement costs and manufacturing cycle time.

ECAD library process improvements. Electronically integrated ECAD model creation process with the New Part Review process decreasing the number of models created for parts not suitable for production. This had the added effect of getting the new part reviews to occur much earlier in the design process and enabling electronic data transfer from ECAD tools to the Product Data Management system.

2.8 Business Practices Roadmap

- Implement a control process for the review of components and assemblies intended for use in new designs. From a Northrop Grumman standpoint, this was a primary goal for the Policies, Procedures and Practices task on the CPOM program. Many new contracts now require OEMs to propose internal parts selection and standardization processes or be subjected to externally imposed controls. Industry attempts to document such procedures have resulted in such documents as EIA-4899, Standard for Preparing an Electronic Component Management Plan, EIA-933, Standard for Preparing a COTS Assembly Management Plan, FAA COTS Risk Management Guide, EIA SSB-1, Guidelines for Using Plastic Encapsulated Microcircuits and Semiconductors in Military, Aerospace and Other Rugged Applications
- Establish a formal New Part Request (NPR) routing and approval process. The i2 Component and Supplier Management tool works well as an automation methodology.
- Link to CAD tools. Any Component or COTS management program must be linked to the design tools if it is to be effective. Without such a link, controls occur too late in the design, adding cost and cycle time to the program development

- Establish component test methodologies and qualification thresholds utilizing industry models and physics of failure analysis.
- Utilize cross functional reviews to assure that design, quality, reliability, manufacturing and business needs are met. Commodity Design Teams were the implementation methodology at Northrop .
- Establish and publish design rules and standard design processes. Common Product Teams were established to address core design processes, design rules and design reuse.
- Design Reviews. Detailed technical design reviews and program reviews are critical to program success. Documentation of these reviews and associated action items provide the necessary discipline for successful execution.
- Update reliability prediction methodologies and selection rules to accurately address COTs technology. Northrop Grumman reliability evaluated existing models and tools and compared the results to field data to determine the most accurate prediction approach and to established updated procedures.
- Make material costs and manufacturing costs visible to the designer. Many companies charge designers with Design to Cost goals. Making basic material and manufacturing costs available is a must if cost is a requirement.
- Establish a referee. NPR elevation procedures must be in place to settle disputes between the review teams and the program design teams. In Northrop Grumman's implementation, an override request for a rejected NPR must go to the Vice President of Engineering and Manufacturing for mediation.
- Make the preferred parts easy to find. Standard parts lists must be made parametrically searchable and maintained in an electronically accessible, controlled format. The i2 Component and Supplier Management tool is a good means of doing that and offers a great deal of supporting data like detailed component parameters, data sheets and DMS data.
- Focus business influence. Where design complexity does not support the use of standard components, design and procurement activity should be focused on a relatively few preferred suppliers.
- Measure your progress carefully. The old adage that you get what you measure applies when developing metrics. Some do's and don'ts with respect to metrics.
- Establish component test methodologies and qualification thresholds were established utilizing industry models and physics of failure analysis.
- Percentage of Standard Part List (SPL) parts on new parts listings. This is an indication of both the robustness of the SPL and the degree to which designers are looking at it. If improperly interpreted, tracking this metric can lead to a large, out of control list of standards.

- Percentage of SPL parts on maturing programs. This is an indication of the growth of the SPL towards the design direction. Program usage is clearly a criterion for SPL addition.
- Number of times the SPL is accessed. Measures the overall program success. Low access rates can indicate either a lack or training or an inadequate SPL.
- Percentage of SPL parts on Corporate Contract. Prenegotiation of purchase orders for standard parts reduces procurement costs, reduces procurement cycle time by enabling automation of purchase orders and encourages designers to use the standards.
- Monitor SPL activity: Number of changes, SPL reviews (DMS, Cost…) In order to be viable, an SPL must be monitored and kept up to date. The SPL itself should be handled like a program bill of materials and design reviews performed routinely with both designers and suppliers.
- NPR cycle time: New Part Request review cycle time must be held to a level that can be tolerated by design and production
- Number of NPRs. Simply counting new part requests and holding designers to a specific limit could result in designs using older technologies
- Number of new parts introduced. This is one of the easier metrics for assessing cost impact. Northrop Grumman uses the Coopers and Lybrand data for cost modeling purposes
- Standard Part Usage must be enabled by getting SPL parts into Engineering Storerooms, onto corporate contracts and into ledger or supplier managed inventory programs
- Number of design revisions. This is another common metric that can backfire if not used carefully. Grading engineers on the number of revision notices to a Bill of Materials can result in revision notices being held for batch processing. If at a production stage, this can result in hardware or materials that don't meet the application requirements. Reasons for revision notices must be taken into account.

2.9 HURDLES TO DESIGN PROCESS OPTIMIZATION

The largest impediment for programs moving from legacy military design practices to optimized design practices is in recognizing the need for process and tool enhancements. Performance contracts, the use of COTS in harsh environments, accelerated obsolescence of technologies and lean business objectives demand critical changes in design practices. As is said about many illnesses, admitting the problem is half the battle. Once a program/corporation acknowledges the issues, executive level management support is required to drive the documentation of repeatable processes, the automation of those processes and the implementation of a metrics monitoring program. Lacking top level support, internal politics and inadequate communications will severely inhibit progress even if company visionaries

understand the details. In turn, metrics monitoring programs make project benefits visible and hold executive interest.

Without documented processes, automation is not possible. In fact, automation can be detrimental in those circumstances. As the defense industry consolidates, companies acquire various design processes and tools. A concerted effort is required to drive related segments of the business to standard tools and processes. Having done that, information flow and process automation can be addressed.

Designers and business managers are faced with multiple data sources and heterogeneous design information. Typically, only a few data experts exist who know how to find all of the information applicable to a given problem. Data sources must be integrated in a manner that makes information readily available to the user. The fewer human interfaces required in the data flow, the fewer the errors that will be introduced. The bottom line is that businesses must define data requirements and dataflow in much the same as processes.

Discipline and metrics are the final keys to be addressed. As with physics, business tends towards disorganization unless forcefully directed otherwise. Design process documentation and tool standardization are of little benefit if they are not used. Design reviews and process reviews are requirements of a successful business. Similarly, those reviews must present viable metrics that can be monitored for further process enhancement. None of this happens of its own accord. Disciplined design only occurs when it is required by corporate, program, and functional management.

3.0 METRICS

Baseline Legacy System and Compare to Pilot. The CPOM Metrics task shows that the use of COTS parts together with implementation of best practices, polices and procedures and new DMS management tools has had both a positive and negative impact on cost avoidance in the design, manufacturing and sustainment of military electronic hardware.   However, we believe the data shows more of a positive than negative impact.

Material cost has decreased 50% while design complexity has doubled on average.   This has allowed more capability in less space at less cost.   The majority of COTS devices are available in packaging ready for automated assembly as compared to military where considerable manual intervention was required.   Thus, we are seeing an average 40% decrease in manufacturing cost with a 10-20% decrease in build time.

The use of COTS parts in new designs is not without its problems.   We are experiencing higher cost in the handling of plastic COTS parts because of moisture sensitivity issues. Moisture exposure is closely monitored and controlled.   In addition, many COTS devices are only available in gold plated leads and are unsuitable for surface mount technology (SMT). Gold leaded parts introduce gold embrittlement reliability issues and are banned from Northrop Grumman SMT manufacturing. Gold leaded parts must be removed from their packaging, hot solder dipped, and repackage before production use.   We are also seeing a 300% increase in the number of DMS occurrences as a result of COTS usage, indicating much shorter life cycles as commercial industry continues to drive the market.   However, cheaper COTS part prices has lowered “life of type buy cost” and lengthened design refresh intervals.

While COTS parts are not without their faults, there is considerable cost avoidance to be realized from their use. However, there is a greater need for better DMS management practices as life cycles shortened and the need for more precise design refresh planning grows.

Table 3-1 Design Metrics

Design Metrics				
Metric		% Change Digital	% Change RF	Comments
1	Number of jumpers	100% decrease	700% increase	3 to1 increase in RF design complexity level
2	Number of design revisions	40% decrease	33% increase	3 to1 increase in RF design complexity level
3	Number of electrical board components	35% increase	25% decrease	RF devices more integrated
4	Number of standard (COTS) parts	N/A	N/A	
5	Number of custom parts	N/A	N/A	
6	Per cent of standard (COTS) parts	50% increase	40% increase	
7	Per cent of custom parts	94% decrease	82% decrease	
8	Number of active parts	N/A	N/A	
9	Number of passive parts	N/A	N/A	
10	Per cent of active parts	8% decrease	47% decrease	RF devices more integrated
11	Per cent of passive parts	5% increase	24 % increase	
12	Redesign time	No change	No change	
13	Redesign complexity	N/A	N/A	
14	Change in electrical part count	N/A	N/A	
15	Build time	20% decrease	10% decrease	
16	Test time	7% decrease	15% increase	3 to1 increase in RF design complexity level
17	First time factory yield	10% increase	33% increase	
18	Factory yield	10% increase	18% increase	
19	Number of DMS last time buys made	N/A	300% increase	COTS life cycles are shorter
20	Number of DMS part replacements	N/A	100% increase	COTS life cycles are shorter
21	Number of new sources developed	N/A	N/A	
22	Number of additional redesigns	N/A	N/A	
23	Age of design	N/A	N/A	

Table 3-2 Financial and Sustainment Metrics

Financial Metrics				
Metric		% Change Digital	% Change RF	Comments
1	Material cost	50% decrease	60% decrease	
2	Design cost (NRE)	35% decrease	45% decrease	
3	Production cost	55% decrease	35% decrease	
4	Test cost	5% decrease	20% increase	3 to1 increase in RF design complexity level
5	Repair cost	26% decrease	38% increase	3 to1 increase in RF design complexity level
6	DMS last time buy cost	N/A	100% increase	COTS life cycles are shorter
7	Sell Price	47% decrease	32% decrease	
Sustainment Metrics				
Metric		% Change Digital	% Change RF	Comments
1	Predicted reliability (LRU)	66% increase	280% increase	
2	Demonstrated reliability (LRU)	290 % increase	N/A	
3	Number of failures	N/A	N/A	
4	Number of repairs	N/A	N/A	
5	Number of DMS parts	N/A	300% increase	COTS life cycles are shorter
6	Per cent of DMS parts	N/A	300% increase	COTS life cycles are shorter
7	Planned redesigns vs unplanned	N/A	N/A	
8	Predicted component obsolescence	N/A	N/A	
9	Predicted board/module/SRU obsolescence	N/A	N/A	

3.1 Cost Avoidance

- 40% - 50% increase in the use of COTS parts
- 80% - 90% decrease in the use of custom parts
- 10% - 20% decrease in build time
- 10% - 30% increase in first time factory yield
- 300% increase in DMS occurrences
- 200% average increase in reliability

3.2 Cost Savings

- 50% - 60% decrease in material cost
- 35% - 45% decrease in redesign cost (NRE)
- 35% - 55% decrease in production cost
- 30% - 40% decrease in sell price

4.0 CONCLUSIONS

CPOM was extraordinarily successful in documenting greater than **22 million dollars in annual cost reductions from processes and tools**. These reductions have been reflected in Northrop Grumman quoting procedures thereby benefiting all new proposals.

Key CPOM activities contributing to the cost savings were: enhanced reliability modeling, Commodity Design Teams, Common Product Teams, improved thermal design, improved material handling and improved manufacturability. These enhancements have been incorporated into design processes to enable COTS technologies

Key CPOM tool activities included: Poet - process and tool integration, metrics, MOCA - obsolescence planning and cost minimization, RADSS - obsolescence management and decisions, I2 – CDT/CPT workflows, DMS data, parametric searching, Rosetta - design capture, process modeling and VectorGen - test vector generation. These tools effectively address real-world concerns. Several have been incorporated into standard Northrop Grumman processes and a couple of more have stimulated interest for intrasector tool deployment.

CPOM metrics gathering demonstrates program impact on:

> 23 major product developments

> 11 Antennas

> 19 Transmitters

> 24 Processors

> 10 Low Power RF

> 3 Inertial Measurement Technologies

> 22 Power Supplies

> 200 Digital and Microwave Boards

Throughout its nearly five-year span, CPOM has been of great benefit to Northrop Grumman and to our customers. The processes and tools developed here have resulted in lower cost, more reliable, and more sustainable products. Northrop Grumman has appreciated the opportunity to work with AFRL ManTech and would be pleased to carry on these initiatives in the future.